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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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INVESTIGATION OF THRUST LOSSES DUE TO SHANKS OF A FLARED-SHANK TWO-BLADE PROPELLER ON A SLENDER-NOSE AIRPLANE

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SUMMARY

Flight measurements of thrust losses due to shanks have been made on a flared-shank two-blade propeller mounted on an airplane with a streamline slender nose.

Thrust losses due to the shanks were found to be high; they were of the order of 9 percent at an airplane Mach number of 0.7 when the propeller was operating at the highest test power coefficient of 0.17 per blade. Loss in thrust due to shanks was a function primarily of airplane Mach number and was relatively independent of blade loading. A 19-percent-larger-diameter spinner, used with the same propeller on another airplane, reduced shank losses by about 60 percent.

INTRODUCTION

Previous flight tests (reference 1) have shown large thrust losses, especially at high speeds, with round-shank propellers. Attempts have been made to reduce these losses by various methods such as the use of propeller cuffs or of shank sections giving rapid transition from thin airfoil sections to round blade roots.

The propeller blade tested represents a design obtained by the method incorporating the rapid transition from thin airfoil sections to round blade roots, as illustrated in figure 1. During a general investigation of this blade, thrust losses due to propeller shanks were investigated. This paper presents measurements and a discussion of these losses. Tests were made at airplane Mach numbers from 0.3 to 0.7 for power coefficients per blade of 0.07 and 0.17 with a propeller speed of 1120 rpm.

Some limited measurements of shank drag with the same propeller blade design on another airplane were made to determine the effect of increasing the spinner diameter.

SYMBOLS

b	blade width (chord)
C_L	design lift coefficient
C_P	propeller power coefficient $\left(\frac{P}{\rho n^3 D^5}\right)$
C_T	propeller thrust coefficient $\left(\frac{T}{\rho n^2 D^4}\right)$
$\frac{dC_T}{d(x_s)^2}$	element thrust coefficient
D	propeller diameter
h	blade-section maximum thickness
J	advance ratio (V/nD)
M	forward Mach number
M_t	propeller-tip Mach number
n	propeller rotational speed, revolutions per second
P	engine power supplied to propeller, foot-pounds per second
q_c	impact pressure
R	propeller-tip radius
r	radius to a blade element
r_s	radial distance from thrust axis to survey point
T	propeller thrust
V	forward speed

x	fraction of propeller-tip radius (r/R)
x_s	fraction of survey radius (r_s/R)
β	blade angle at any radius, degrees
ΔH	change in total pressure
η	propeller efficiency $\left(C_T J/C_P\right)$
ρ	density, slugs per cubic foot
$\Delta\eta$	loss in propeller efficiency $\left(\frac{\Delta TV}{P} = \frac{\Delta T}{T}\eta\right)$
ΔT	negative propeller thrust

APPARATUS AND METHODS

The propeller was tested in a two-blade configuration. Blade-form curves for this propeller are shown in figure 2. Figure 3 shows details of the shank sections and spinner juncture. The propeller had a diameter of 11 feet 1 inch, NACA 16 series airfoil sections, a design lift coefficient of 0.5, and a blade activity factor of 130.

The airplane used was a fighter airplane with a streamline slender nose. Figure 1 shows the propeller mounted on the airplane. The spinner was modified slightly by fairings used to cover the two unused stubs of a four-blade hub. These fairings projected above the contour of the spinner by a maximum of about $1\frac{1}{8}$ inches.

Propeller thrust was measured by the slipstream total-pressure survey method described in reference 2. The survey rake was located about $3\frac{1}{2}$ feet from the plane of the propeller and is shown in figure 1. Additional survey tubes were installed near the fuselage to measure more accurately the total pressures in the shank-survey region. Propeller torque was measured by an NACA hydraulic torque meter. Standard NACA recording instruments were used to determine engine speed, impact pressure, static pressure, and free-air temperature.

Tests were made at airplane Mach numbers from 0.3 to 0.7 for power coefficients per blade of 0.07 and 0.17 with a propeller speed of 1120 rpm.

RESULTS AND DISCUSSION

Thrust-distribution curves for a typical low-speed run and a typical high-speed run are presented in figures 4(a) and 4(b), respectively. The negative areas have been hatched to indicate thrust losses as defined in this paper. These thrust losses are composed of losses attributed to the blade shanks and an apparent loss due to the fuselage boundary layer. Theoretical calculations indicate that this boundary layer is less than 1/2 inch in thickness.

Shank losses, as determined by integration of the negative thrust areas (excluding the boundary layer), are presented in figure 5(a) as the variation of $\Delta T/q_c$ with airplane Mach number. Shank loss appears to be relatively independent of blade loading. The increase of about 50 percent in $\Delta T/q_c$ with Mach number over the Mach number range is considerably less than would be expected from two-dimensional tests of thick sections, and this result is believed to be due to three-dimensional relief effects experienced at the propeller shanks.

In figure 5(b) shank losses are presented as losses in propeller efficiency $\Delta\eta$. In the determination of the loss in efficiency, the power absorbed by the shanks was assumed to be small. Efficiency loss is shown to increase rapidly with Mach number. For example, at a power coefficient of 0.17 per blade and an airplane Mach number of 0.7, a loss in efficiency of 9 percent due to shanks was measured. This efficiency loss is due in part to the increase in shank loss with speed and in part to the reduction in total thrust with speed at constant power (fig. 5(c)). Because of this latter effect, the efficiency loss would have increased with speed even if the shank loss had been independent of Mach number (see fig. 4); the increasing importance of reducing shank losses as the speed is increased is thus emphasized. Figure 5(b) also shows that efficiency loss due to poor shanks increases as the power is reduced because of the corresponding reduction in total thrust.

Measured propeller efficiencies (corrected for slipstream rotation) including shank losses for the two test power coefficients are presented in figure 6. Also given are the propeller efficiences with shank losses neglected. These results indicate that, even at high speeds, efficiencies of the order of 90 percent can be attained if shank losses can be eliminated.

Shank losses can be reduced either by covering the thick shank sections or by improving the sections aerodynamically. Thick shank sections may be covered by increasing the spinner diameter. Arbitrary increases in spinner diameter tend to increase structural problems but, since the worst region of shank loss occurs inboard, relatively small increases in spinner diameter can reduce shank losses appreciably. An idea of the effects that could be accomplished by increasing the spinner diameter was obtained from some limited measurements of shank drag with the same propeller blade design on another slender-nose fighter-type airplane which has a 19-percent-larger spinner. In figure 7, a comparison is given of the loss in total pressure as a fraction of free-stream impact pressure with radial distance for the two installations. In order to make the measurements directly comparable, the two sets of data are plotted along the propeller radius rather than along the radius at the survey plane. Survey data obtained at any specific distance from the fuselage side were assumed to apply to a propeller section an equal distance from the spinner surface. By use of a larger-diameter spinner, part of the inboard negative thrust was eliminated. At an airplane Mach number of 0.67, negative thrust was reduced about 60 percent. (See fig. 7.) Although the spinner shapes of the two airplanes were slightly different, a slight difference is probably caused in radial velocity distribution in the plane of the propeller; this difference should not appreciably change the measured 60-percent improvement.

The larger-diameter spinner required slightly larger cut-outs for the propeller shank sections. The effect on propeller efficiency of cut-outs merits some discussion. If the spinner diameter were increased to a propeller radius at which sections were producing lift and thrust, the effect of the cut-out would no doubt lower the efficiency of the section and a suitable seal at the spinner-shank juncture would be required. A suitable seal is especially needed if the sections are thin at the spinner juncture. For points at which the propeller sections produce mainly drag, the cut-out may relieve the pressures producing it and thereby increase the over-all efficiency. If these factors are taken into account in the design of a propeller-spinner combination, a better design might be obtained.

CONCLUSIONS

Tests of a flared-shank two-blade propeller mounted on a slender-nose airplane led to the following conclusions:

1. Thrust losses due to the shanks of the propeller blade were high; they were of the order of 9 percent at an airplane Mach number of 0.7 when the propeller was operating at the highest test power coefficient of 0.17 per blade.

2. Loss in thrust due to shanks was a function primarily of airplane speed and was relatively independent of blade loading.

3. An increase in spinner diameter of 19 percent reduced thrust losses at the shank sections by about 60 percent.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 19, 1947

REFERENCES

1. Vogeley, A. W.: Flight Measurements of Compressibility Effects on a Three-Blade Thin Clark Y Propeller Operating at Constant Advance-Diameter Ratio and Blade Angle. NACA ACR No. 3G12, 1943.

2. Vogeley, A. W.: Climb and High-Speed Tests of a Curtiss No. 714-1C2-12 Four-Blade Propeller on the Republic P-47C Airplane. NACA ACR No. L4L07, 1944.

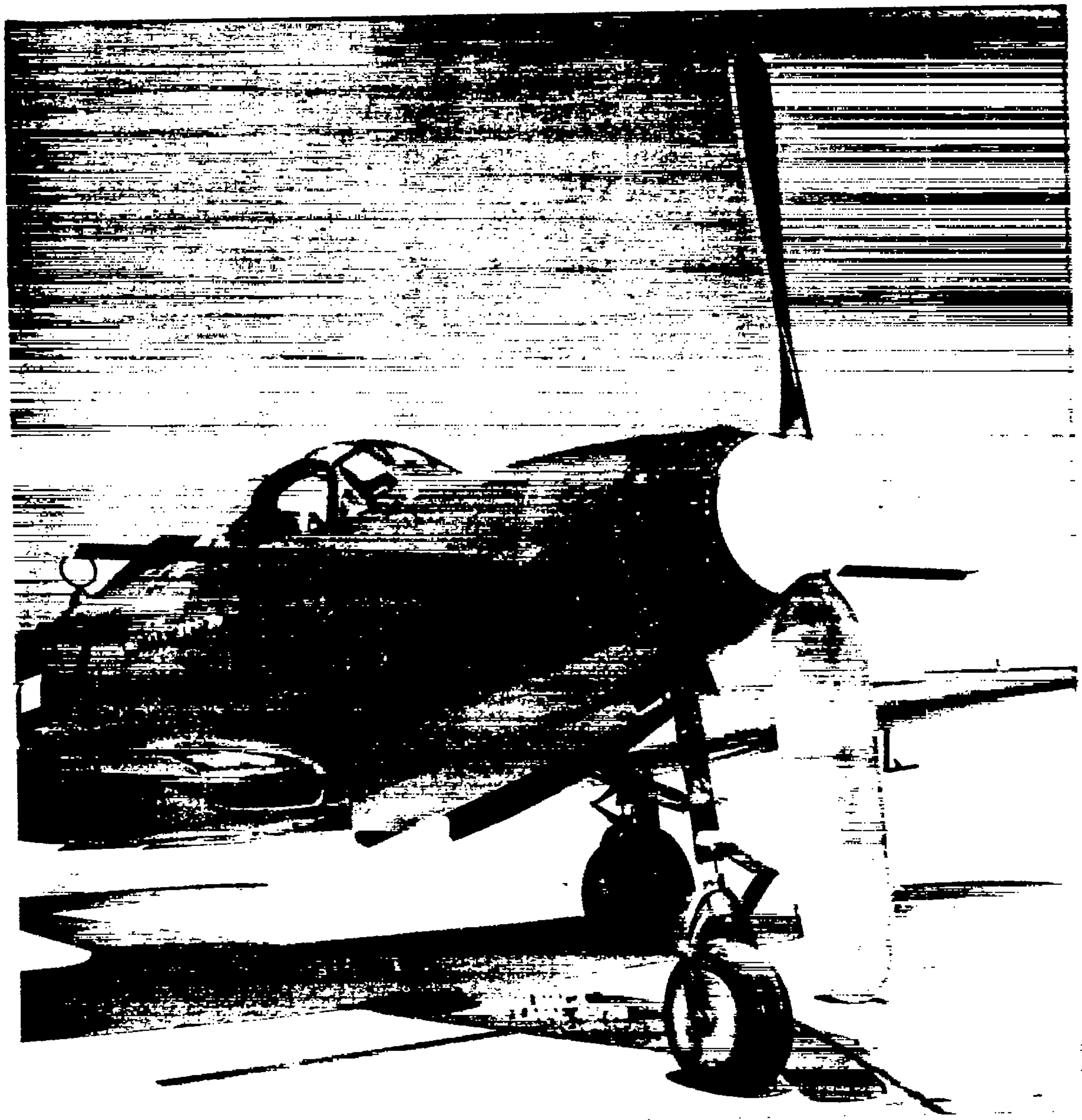


Figure 1.- General view of propeller mounted on airplane showing rapid transition from thin airfoil sections to round blade roots.

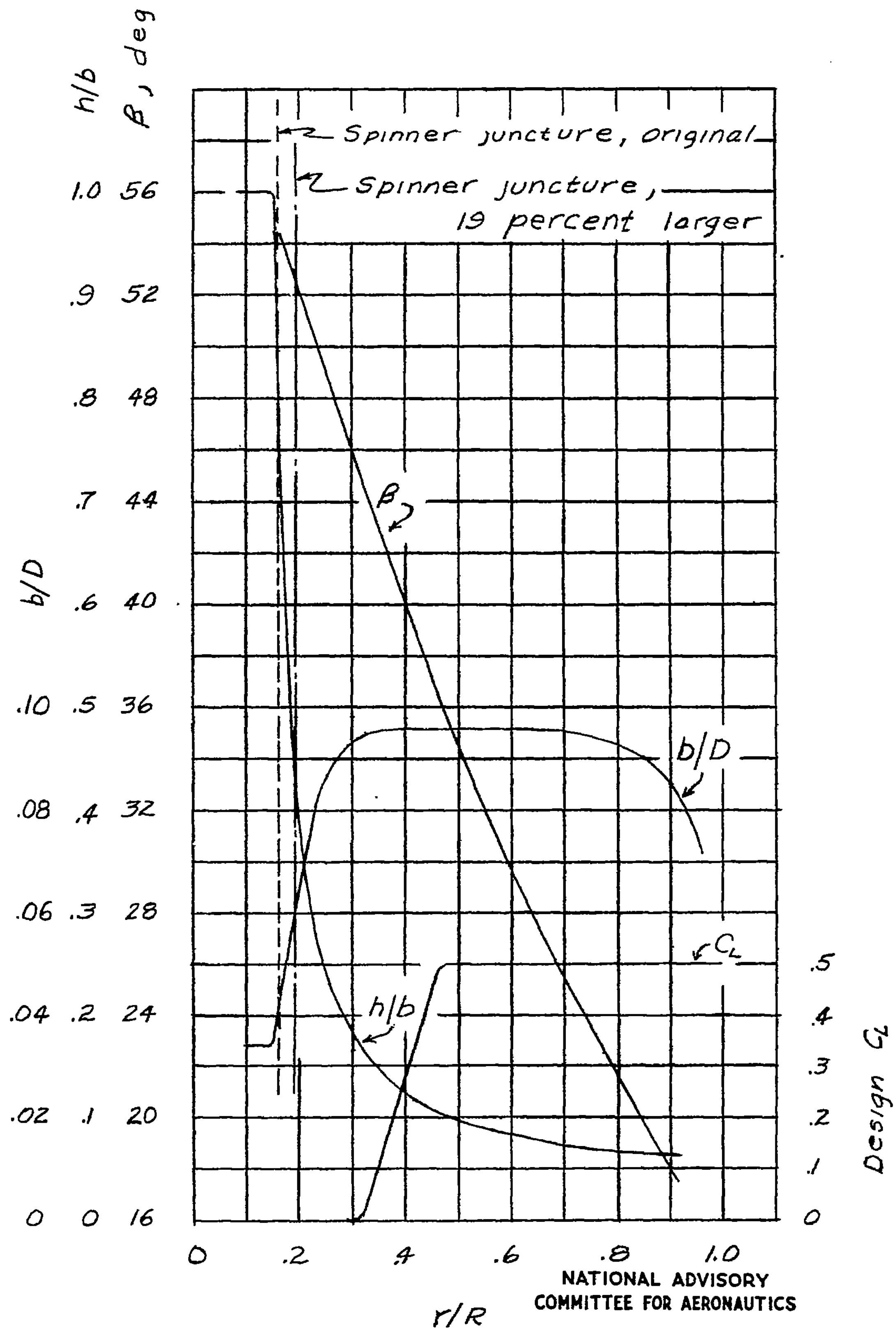


Figure 2.- Blade-form curves for propeller tested.

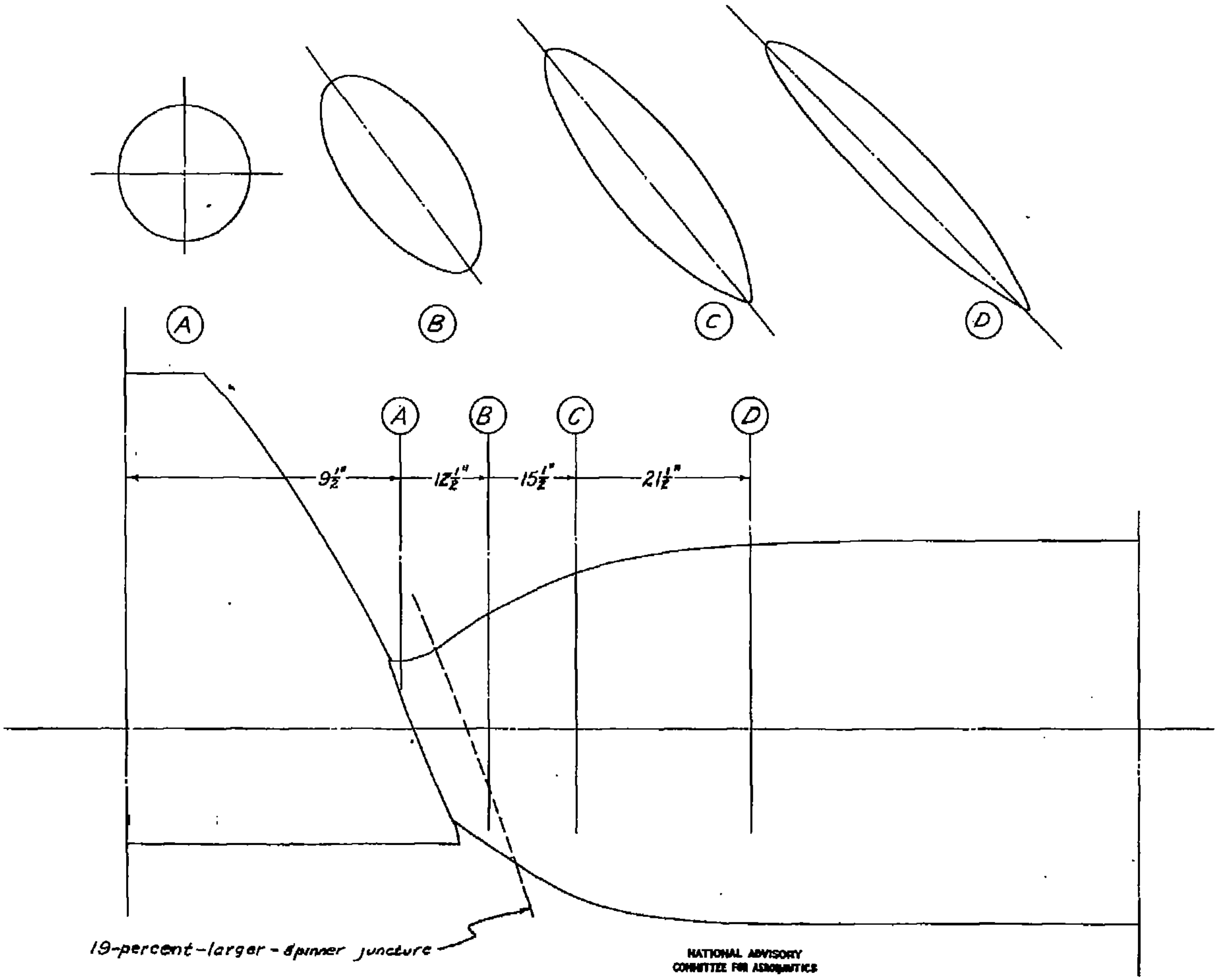
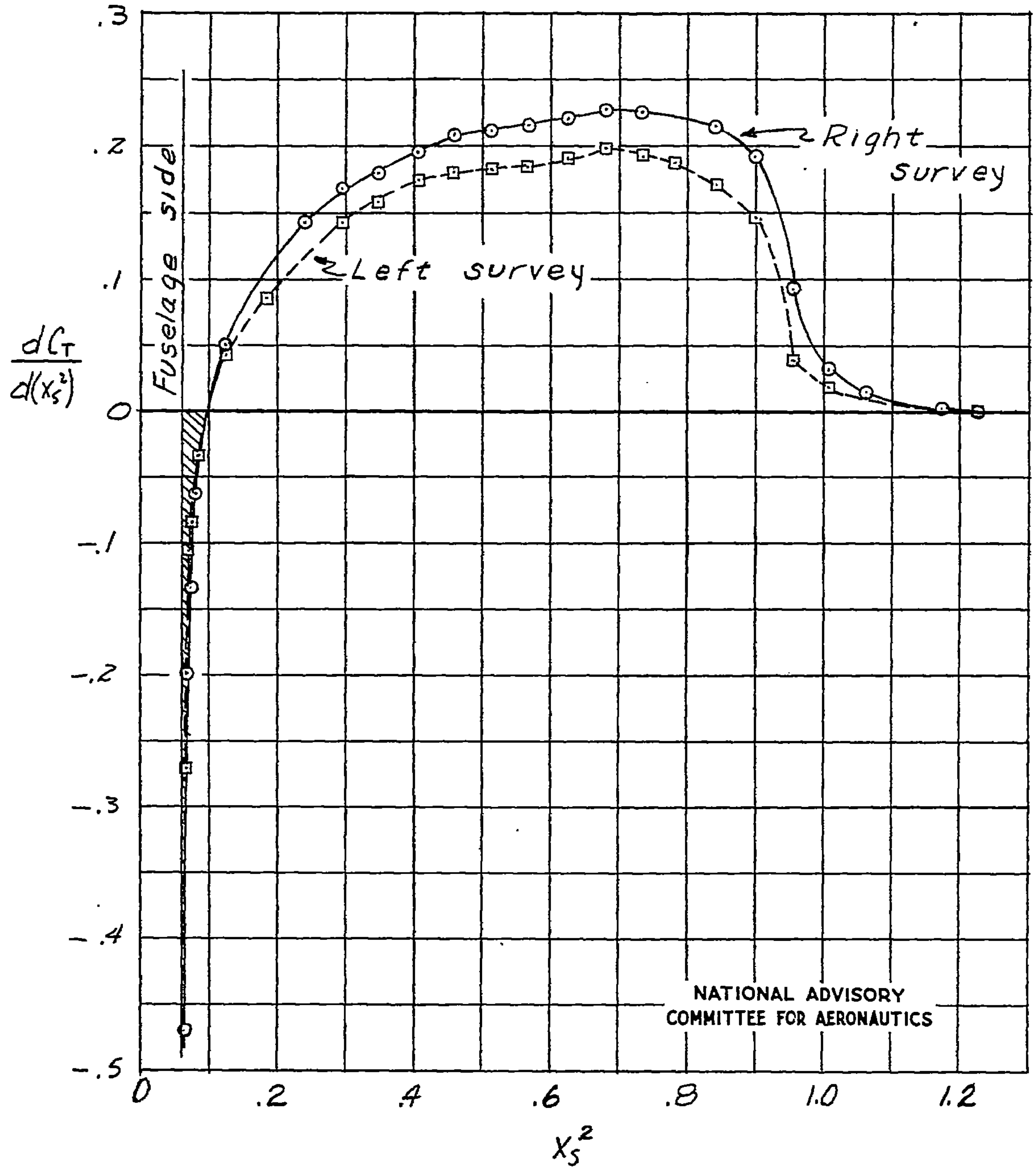
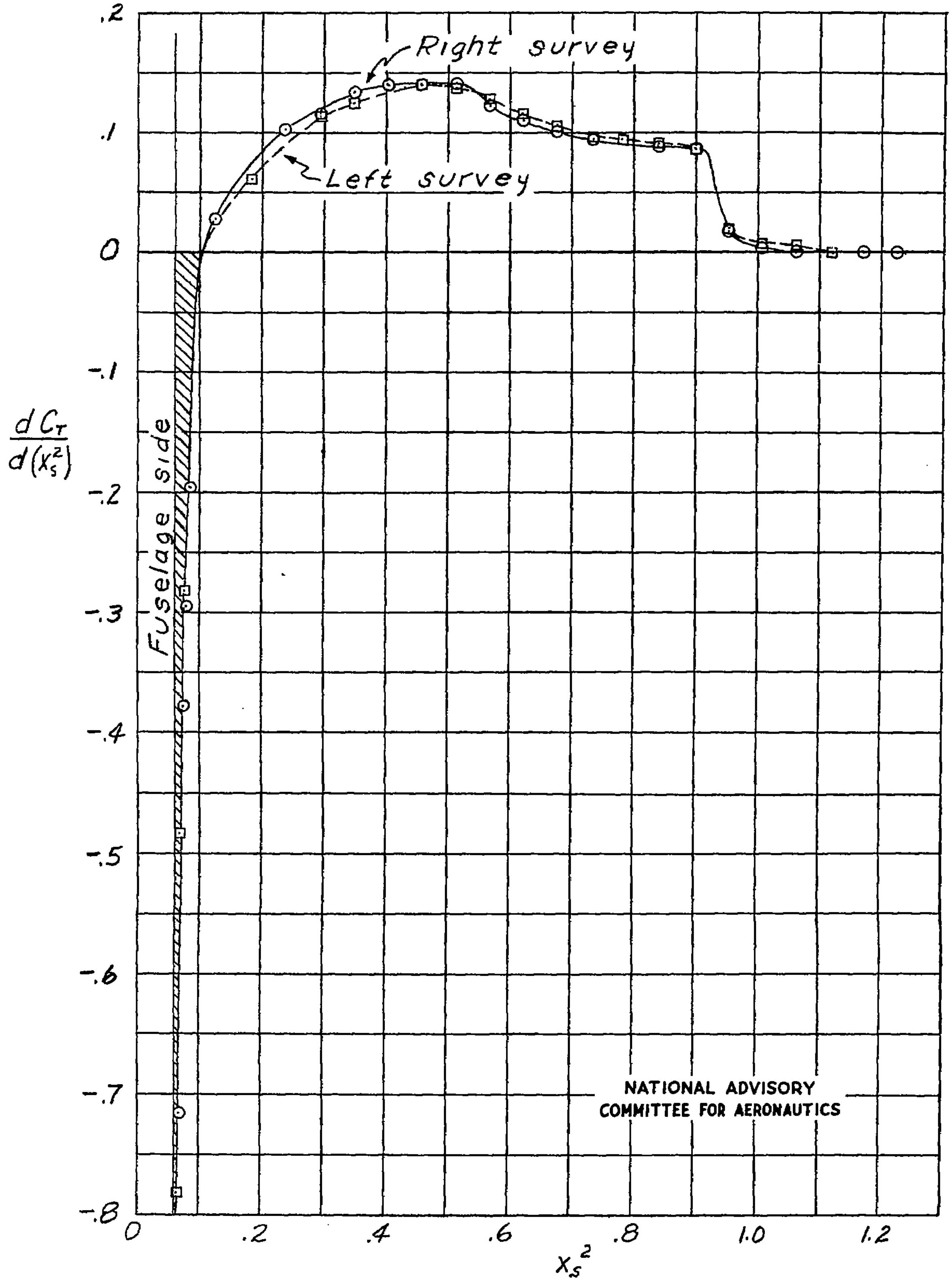


Figure 3.- Details of shank sections and spinner juncture.



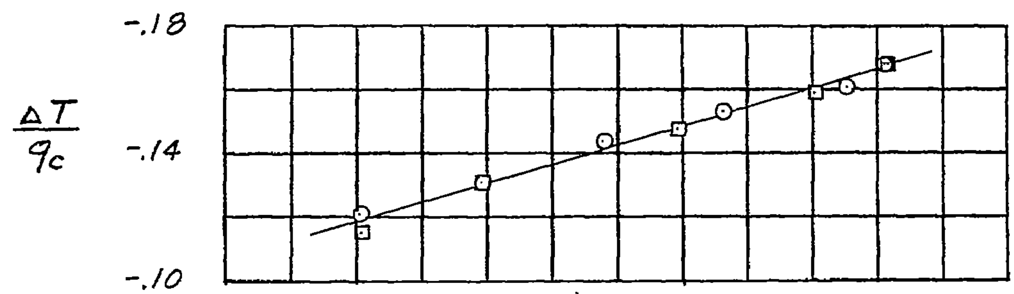
(a) Low-speed run. $J = 1.899$; $C_P = 0.323$; $C_T = 0.141$; $\eta = 0.837$; $\Delta\dot{\eta} = 0.011$; $M = 0.396$; $M_t = 0.765$.

Figure 4.- Thrust-distribution curves.

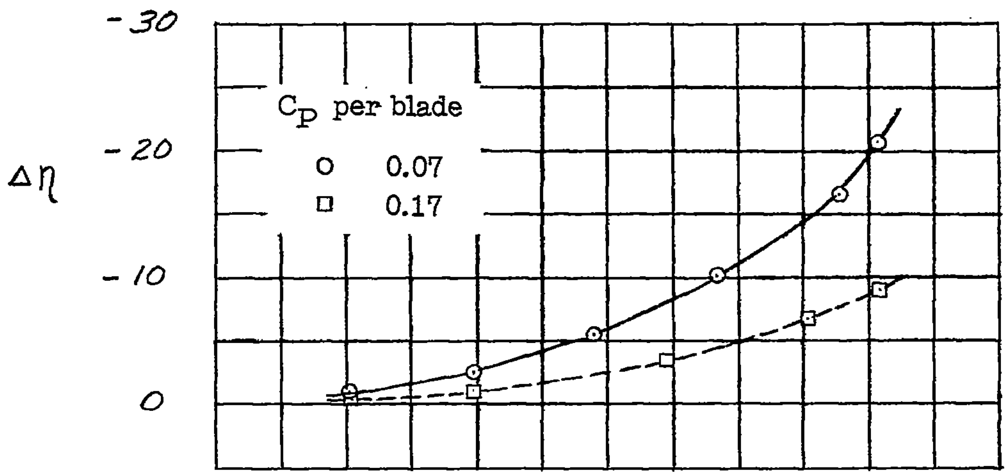


(b) High-speed run. J = 3.416; C_P = 0.336; C_T = 0.079; η = 0.815; $\Delta\eta$ = 0.094; M = 0.709; M_t = 0.961.

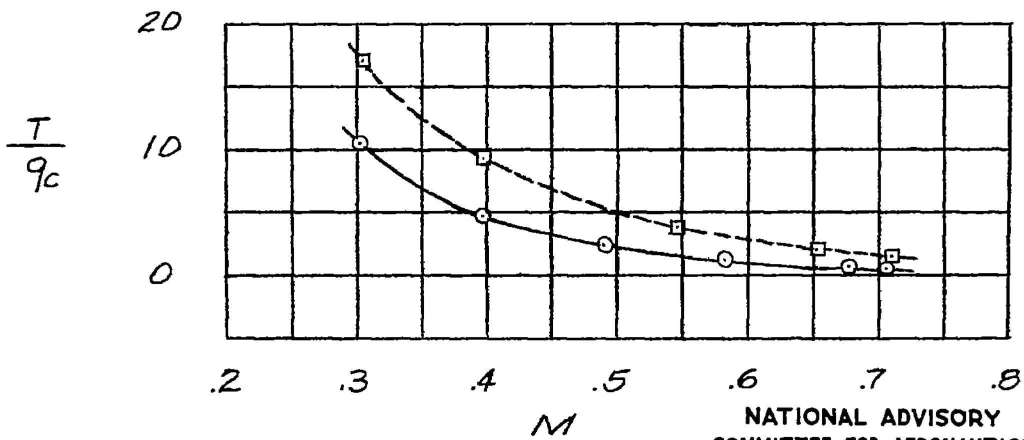
Figure 4.- Concluded.



(a) Shank losses in terms of $\frac{\Delta T}{q_c}$.



(b) Shank losses in terms of propeller efficiency.



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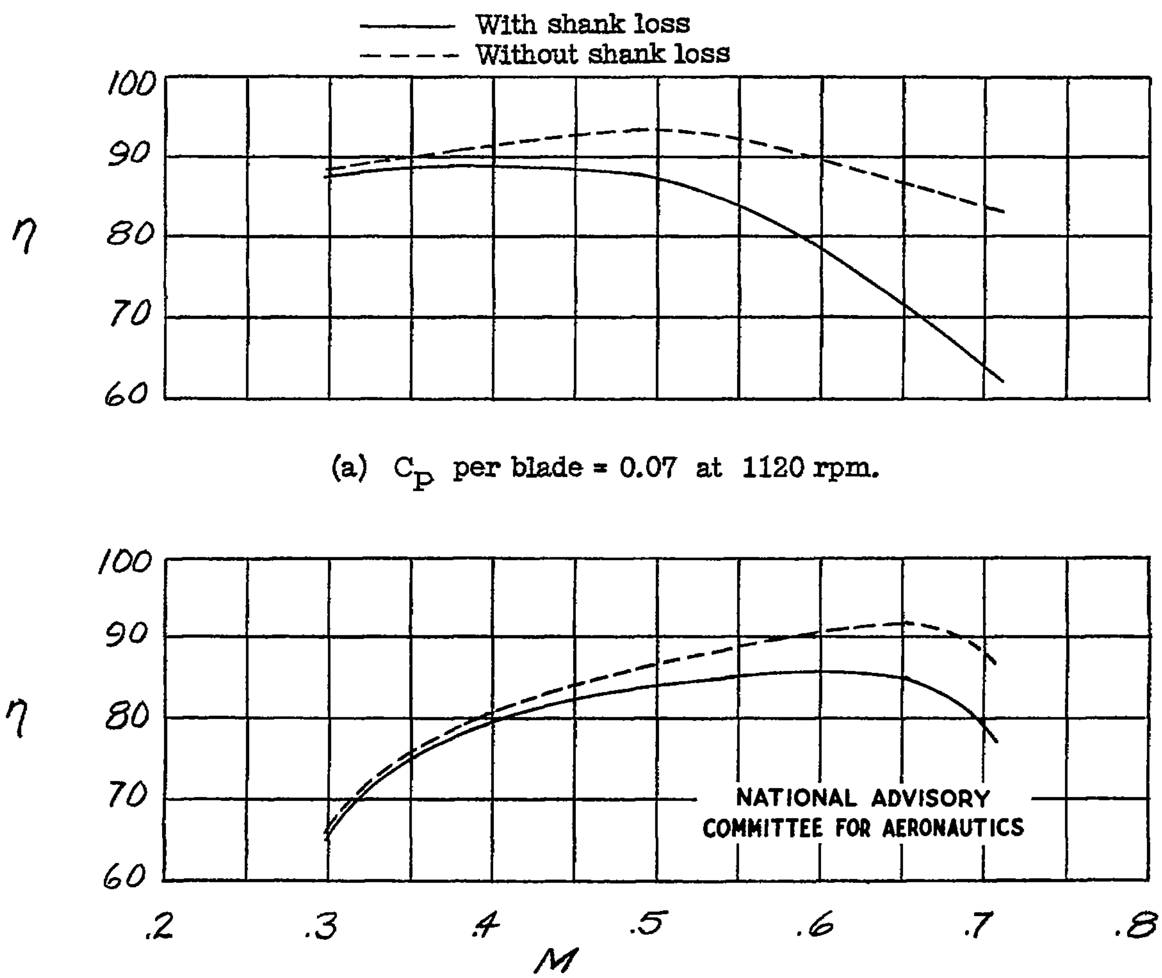
(c) Total-thrust curves.

Figure 5.- Shank losses measured with a flared-shank two-blade propeller on a slender-nose airplane. Propeller rotational speed, 1120 rpm.



(a) C_P per blade = 0.07 at 1120 rpm.

(b) C_P per blade = 0.17 at 1120 rpm.

Figure 6.- Propeller efficiency curves for the propeller blade tested.

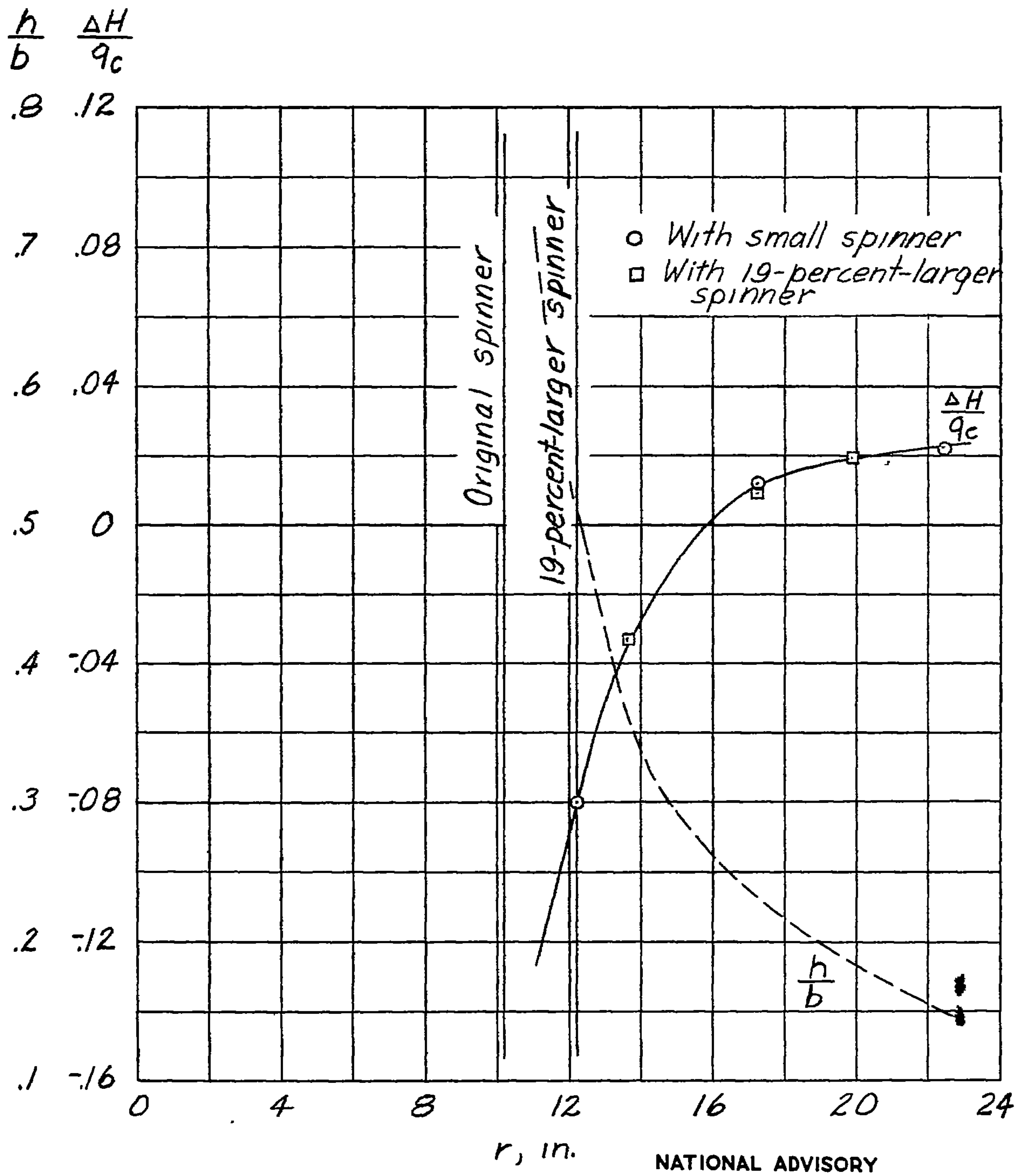


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Figure 7.- Comparison between total-pressure loss due to shanks for original and 19-percent-larger spinner. $M = 0.67$; C_P per blade = 0.13; $J = 2.83$.